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PERFORMANCE OF EMISSIONS CONTROL SYSTEMS ON MUNICIPAL WASTE COMBUSTORS

BY

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16. ABSTRACT The paper reports results of several EPA-supported field evaluations of data on gaseous pollutant emissions from modern municipal waste combustors/incinerators and emissions control by flue gas cleaning systems. The results are presented in terms of acid gas (HCl and SO2), trace organic (dioxin/furan), trace heavy metal, and particulate matter reductions through the use of lime spray dryer absorber/fabric filter and lime spray dryer absorber/electrostatic precipitator technologies. Plans for additional field tests are discussed briefly.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Pollution	Particles	Pollution Control	13B	14G
Flue Gases	Calcium Oxides	Stationary Sources	21B	07B
Waste Disposal	Filters	Municipal Waste Combustors	15E	
Combustion	Fabrics			11E
Incinerators	Electrostatic Precipitators	Acid Gases		
Organic Compounds		Particulate	07C	13I
Furans	Sulfur Dioxide	Fabric Filters		

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ABSTRACT

The development of regulations for municipal waste combustors (MWCs) under Section 111 of the Clean Air Act is underway. Part of this EPA effort involves obtaining data on gaseous pollutant emissions from combustors/incinerators and emissions control by flue gas cleaning systems. Several EPA-supported field evaluations have recently been performed on modern MWCs, and the results of these tests are reported. The results are presented in terms of acid gas (HCl, SO_2), trace organic (dioxin/furan), trace heavy metal, and particulate matter reductions through the use of lime spray dryer absorber/fabric filter and lime spray dryer absorber/electrostatic precipitator technologies. Plans for additional field tests are also briefly discussed.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

INTRODUCTION

In July 1987, the EPA Administrator's decision to further regulate municipal waste combustors (MWCs) under Section 111 of the Clean Air Act was published in the Federal Register. (1) This announcement was made concurrently with a Report to Congress (2) which summarized information gathered by EPA on MWC emissions: combustion practices to control organics; flue gas cleaning technologies; , sampling and analysis methods; risk assessment; and MWC population, distribution, and projections. The emissions data base in the study for Congress focussed on four air pollutant categories: acid gases (HCl, SO_2), trace organic compounds (primarily dioxins and furans), trace metals, and particulate matter. The report helped influence the structure of the EPA field test program by revealing areas where additional data were needed to support EPA's regulatory development effort. The report also included the availability of test sites where modern MWC technology was being used.

Major components of the on-going EPA field test program are to characterize and to determine the performance of flue gas cleaning systems used with modern MWC units in the U. S. The focus of the work reported here is to discuss the results of the flue gas cleaning system tests. In the EPA program, effective flue gas cleaning is being studied as a complement to efficient municipal solid waste (MSW) combustion for minimizing air pollutant emissions as well as total pollutant emissions. The fact that modern flue gas cleaning systems can effectively reduce pollutant emissions from MWCs should not preclude minimizing combustor emissions through employing good combustion practices, such as have been reported earlier. (3) Consequently, in the EPA field tests, the combustion control of pollutants, as well as the effectiveness of the flue gas cleaning system, in removing one or more of the four pollutant categories noted earlier were studied where possible.

In the U.S., state-of-the-art MWC units now often use a lime spray dryer absorber (SDA) for acid gas control in conjunction with either a fabric filter (FF) or an electrostatic precipitator (ESP) for particulate matter control. These dry scrubber combinations are also effective in removing the other pollutant categories listed above. Thus, the field test results reported here represent emissions from MWC units equipped with dry scrubbers and their performance.

The objectives of the tests discussed here were:

1. To determine the pollutant concentrations and the control of emissions during permit compliance tests,

2. To evaluate the performance of a SDA/FF system for selected SDA outlet (or FF inlet) gas temperatures, and

3. To characterize selected pollutant emissions leaving the combustor and entering the SDA.

TEST PROGRAM

The major portion of the EPA field test program currently encompasses five sites and involves three mass burn and two refuse-derived fuel (RDF) units. Two of the mass burn units (Marion County, OR, and Millbury, MA) are conventional waterwall energy recovery units, for which the EPA tests have been completed. The Marion County unit has a SDA/FF (Teller) system, and the EPA tests involved collection of chlorinated dibenzo-p-dioxin (CDD) and chlorinated dibenzo-furan (CDF) data during the September 1986 compliance tests (4) and shutdown and start-up tests in June 1987 (5) and data on other pollutants during the June 1987 characterization tests. (6) Because of low internal standard recoveries in the CDD/CDF analysis for samples at the spray dryer absorber inlet in EPA's September 1986 test, additional inlet gas samples were collected in February 1987. The results from the later samples are reported here and are believed to be representative as the combustor was still relatively new and operating under conditions similar to the September 1986 tests. The Marion County parametric tests were to consist of two planned phases, characterization and performance. The characterization phase was to evaluate a variety of combustor operating conditions as well as temperature conditions for the SDA/FF emission control device. However, the performance test phase was not undertaken because modifications to the system to allow independent control of the approach to saturation temperature and reagent (stoichiometric) ratio were not completed by the facility.

The tests on one of the two units at Millbury, MA, were made during permit compliance testing in February 1988. The EPA sponsored the collection of CDD/CDF samples at the inlet to the SDA and the facility sponsored the collection of similar samples at the outlet of the ESP. (7) These tests were performed by the same contractor. The third mass burn unit, Montgomery County South in Dayton, OH, is a refractory wall unit with a rotary kiln combustor and without energy recovery, but designed to permit installation of a recovery boiler later if desired. The incinerator which is similar in design to Volund refractory incinerators is composed of a primary ignition and combustion chamber, a rotary kiln, a secondary mixing chamber where combustion is completed, and a spray quench chamber. EPA-supported tests in Dayton began in late October 1988 and address limestone injection into the primary combustion chamber ahead of the rotary kiln and in-duct sorbent injection into the humidified flue gas prior to its entry into an ESP. The results of the tests should be available in 1989.

Both RDF unit tests for EPA were made during permit compliance tests: the tests on the Biddeford, ME, unit in December 1987 (8), and those on the Mid-Connecticut unit in Hartford in July 1988. (9) Characterization and performance tests on the same unit in Hartford are scheduled for later this year and early in 1989 as part of a joint Environment Canada/EPA project.

Table 1 provides information on units tested thus far in the EPA field test program. As noted earlier, additional testing is planned on the Mid-Connecticut unit, and testing on the new Montgomery County South unit has just started.

Figures 1-4 are process diagrams for the test sites noted in Table 1. Sampling locations referenced in Table 2 are shown in these figures.

The samples collected during the test program may be placed into two main categories: flue gas samples and process stream samples. Table 2 summarizes the emission measurements obtained from the flue gas samples by both manual methods and instruments, as well as those from the process stream samples (ash, residue, lime slurry, and Tesisorb). An integral part of all testing was the monitoring and recording of process data. These data typically included combustor operating conditions (air flow and its division as underfire and overfire air, gas temperature at selected points, steam flow rather than fuel feed rate, CO, O_2, and CO_2), spray dryer absorber inlet temperature and gas component concentrations (SO_2, O_2, and NO_x), and particulate collector outlet temperature and gas component concentrations. The process stream data were generally obtained in part from facility measurements and in part from measurements using test contractor or EPA equipment. In most cases air emission test measurements were subject to EPA quality control and quality assurance requirements.

DISCUSSION OF DATA AND RESULTS

Data on HCl concentrations in the flue gas (all corrected to 12% CO_2) were collected at all four sites. The average data for each run, as well as temperature data, are shown in Table 3 along with pertinent temperatures and removal efficiencies. The overall removal efficiency (in spray dryer absorber plus particulate collector) averaged 90.7% for the baseline tests at Marion County when the HCl inlet concentration averaged 639 ppmv and the SDA outlet temperature was 300°F. About 75% of the total HCl removal occurred in the SDA. During the tests when the SDA outlet temperature was varied from the baseline value of 300°F, the overall HCl removal changed as expected, decreasing to 78 and 71.5% for 330 and 360°F, respectively, and increasing to 97.5% when the outlet temperature was 262°F. The corresponding HCl removal in the SDA during these three runs ranged from about 58 to 78%.

While the average inlet HCl concentrations at the three other test sites were both higher (Millbury) and lower (Biddeford and Hartford), than at Marion County, the overall HCl removals for all

runs were 98% or greater and the averages for all three sites were 99.1%. The HCl removal in the SDA at Biddeford was 93.2%, or about 94% of the total removal. The SDA average outlet temperatures and particulate collector outlet temperatures were also lower at the three sites than at Marion County. The lowest SDA average outlet temperature (255°F) occurred at Millbury which has a SDA/ESP. The corresponding temperatures at Biddeford and Hartford were 278 and 271°F, respectively. However, the reagent (stoichiometric) ratios at Marion County and Biddeford could not be determined with sufficient accuracy from the data collected to permit definitive system performance comparisons related to sorbent variables at the sites.

Table 4 presents the SO_2 data and results for the Marion County, Biddeford, and Millbury tests. No SO_2 removal data were obtained during the Hartford tests. The average baseline results at Marion County indicated an overall SO_2 removal of 43.7%, about 75% of this in the SDA, for an inlet SO_2 concentration of 429 ppmv (dry, corrected to 12% CO_2). As noted earlier, the lime feed slurry to the SDA is prepared at a fixed solids concentration, and the slurry feed rate is used to control the SDA outlet temperature. Thus, increasing the lime slurry feed rate at a given unit steam load increases the reagent (stoichiometric) ratio and decreases the SDA outlet gas temperature and vice versa. The flue gas cleaning systems at both Biddeford and Millbury are designed to control both the reagent ratio and SDA outlet temperature independently. The average SO_2 removal for all runs at both of these sites was 77.8 and 79.4%, respectively, with Biddeford having an average inlet SO_2 concentration of 91.9 ppmv and Millbury's value being 285 ppmv (both corrected to 12% CO_2). It should be noted that about 45 minutes after Run 2 at Biddeford began, the control room doubled the slurry feed after learning that the SO_2 removal was below its desired value. This change raised the overall removal from 65.9% in Run 1 to 72.4% in Run 2 and 89.5% in Run 3. Thus, the average overall SO_2 removal was 77.8% for the three runs over which the average SO_2 inlet concentration was 91.9 ppmv (dry, corrected to 12% CO_2). The SO_2 inlet concentration at Millbury ranged from 243 to 307 ppmv, with the average overall SO_2 removal ranging from 76.7 to 81.7%. As noted in the discussion on HCl removal earlier, the average SDA outlet temperature was 300, 278, and 255°F at Marion County, Biddeford, and Millbury, respectively.

Based on gas sampling, the CDD/CDF results obtained during normal operation at each site are given, after correction to 12% CO_2, in Table 5. Comparison of the average uncontrolled CDD and CDF results show that the uncontrolled CDF values were at least double the CDD values at all sites. The RDF units had the highest uncontrolled CDD and CDF as well as highest removal of these organics (>99%) in their flue gas cleaning systems. With the exception of Millbury, the CDD removal exceeded 96%, the CDF removal 99%, and

total CDD+CDF removal 98% at all sites tested. Millbury, which recorded the lowest uncontrolled organic emissions, had the lowest average removals, being 66.6, 60.5, and 62.1% for CDD, CDF, and CDD+CDF, respectively. The total controlled CDD+CDF emissions were less than 5 ng/dscm for all sites with exception of Millbury which had a total of 62.2 ng/dscm (CDF = 47.4 ng/dscm). Considering that the average overall HCl and SO_2 controls were very high (99.1% for HCl, 79.4% for SO_2) and the SDA outlet temperature was the lowest (255°F) of the units tested, it is surprising that the highest controlled CDD, CDF, and CDD+CDF emissions for the units tested were obtained for the Millbury unit. The results obtained show that the SDA/FF was very effective for controlling CDD/CDF and that the SDA/ESP as operated at Millbury was less effective than SDA/FF in controlling these pollutants. These results suggest this ESP may not be collecting fine particulate matter as well as a fabric filter since the CDD and CDF are believed to be preferentially attached to or adsorbed on fine particulate matter.

It should be noted that combustion conditions at Biddeford and Mid-Conn were not optimized. Biddeford was experiencing problems with the RDF feed conveyer, resulting in some temporal, non-uniform combustion conditions as evidenced by periodic increases in CO emission levels. Also Mid-Conn had not completed all of their combustor performance tests to optimize the RDF combustor. The less than optimum combustion conditions at Mid-Conn were evidenced by relatively high CO levels. Valid comparisons of relative furnace emissions between RDF and mass burn combustors should only be attempted after optimum operating conditions are obtained in RDF combustors. One should also note that the SDA operation at Marion County had not been optimized at the time of the tests reported so that the Marion County air pollution control device performance may have been poorer than should be expected for SDA/FF systems.

Particulate matter emission and control results are listed for each site in Table 6. The removal exceeded 99%, with Unit 11 at Mid-Conn showing the highest average removal (99.8%) for its three test runs. The average outlet particulate emission ranged from 0.0023 gr/dscf at Marion County to 0.0144 gr/dscf at Biddeford. Marion County also had the lowest particulate loading at the SDA inlet, averaging 0.881 gr/dscf while the two RDF units had higher loadings, as expected because of semi-suspension firing of the RDF. The inlet loading averaged 3.21 gr/dscf at Biddeford and 2.52 gr/dscf at Mid-Conn.

Table 7 summarizes the metals emission data for Marion County, Biddeford, and Hartford, each equipped with a fabric filter. Lead was the predominant uncontrolled pollutant, with cadmium and total chromium alternating as next highest at Marion County and Biddeford. The flue gas cleaning system, which had a cyclone preceding the SDA at Biddeford, removed over 99% of the heavy metals shown in Table 7, except during Run 4 at Marion County when the fabric filter was bypassed and during Run 1 at Hartford when the mercury removal was about 81%. Both RDF units had similar controlled emissions for arsenic, but the average uncontrolled mercury value at Hartford was double that at Biddeford although both units had similar SDA inlet (~ 375°F) and outlet (~ 275°F) temperatures. While mercury removal in the cyclone may have occurred, the probable reason for the large difference in inlet mercury values is due to the RDF feed composition at these sites. Generally, the uncontrolled metal concentrations were higher in the RDF feed (Biddeford) than in the mass burn feed (Marion County). The most significant differences were in the total chromium (412 and 3,080 µg/dscm) and lead (20,000 and 30,400 µg/dscm) concentrations, the higher values in both cases being those for Biddeford.

Since RDF units have higher particulate emissions from their combustion chambers than mass burn units, comparison of metal emissions from these different combustors should also include metal emission rates from the units as percentages of total particulate emissions. Another factor that has to be considered in comparing metal emissions is furnace feed rate. In the tests reported here, the MSW and RDF feed rates were not measured; therefore, metal emissions per unit of feed are not available.

In addition to determining the trace metals removal in the SDA/FF, the trace metal contents of ashes/residues were obtained from the Biddeford tests. The fabric filter residue contained an average lead content of 1,680 µg/g, and its range was 537 to 2,800 µg/g for the three runs. The cyclone ash averaged 2,300 µg lead/g ash, with a range of 2,200 to 2,400 µg/g. The mercury content varied from <28 µg/g in the cyclone ash to 19.5 and <16 µg/g in the fabric filter solids and bottom ash, respectively. Heavy metal concentrations in the lime slurry feed were low, the maximum concentration being 3.8 µg/g for arsenic.

CONCLUSIONS

Based on results from compliance and characterization tests at four modern MWCs, it is concluded that:

1. SDA/FF and SDA/ESP systems are effective in controlling acid gas emissions (HCl, SO_2) when operated within their design limits. These systems can remove 90% or more HCl and 70% or more SO_2.

2. The SDA/FF systems tested were more effective in controlling CDD and CDF emissions than the SDA/ESP system tested. The former systems attained an average CDD removal of 98.7% and an average CDF removal of 99.5% for an average overall removal of 99.4%. The SDA/ESP removed less than 70% of these pollutants although operating with a lower SDA outlet gas temperature.

3. The total CDF concentrations, both uncontrolled and controlled, were generally greater than the total CDD values. The inlet total CDD concentrations for the RDF units were several times greater than those of the mass burn units. However, effective operation of their flue gas cleaning systems resulted in low controlled emissions, even lower than those during some test runs for the mass burn units.

4. Limited trace metal results were obtained, the most extensive set being for the Biddeford unit. Lead was the dominant metal, having the highest inlet concentrations at the inlet to the spray dryer. Cadmium and total chromium alternated as the next highest concentrations at the Marion and Biddeford units, respectively. The flue gas cleaning systems were effective in removing all metals studied by over 99%, except mercury whose removal ranged from 80.6 to 99.7%.

5. All flue gas cleaning systems were effective in removing particulate matter. The average removal efficiencies exceeded 99% for all test runs. The mass burn units, as expected, had lower inlet particulate loadings than did the RDF units.

Table 8 summarizes the removal efficiencies for the different pollutants at the facilities tested.

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APPENDIX

CONVERSION FACTORS

Readers more familiar with metric units may use the following to convert the non-metric units used in this paper.

Non-Metric	Times	Yields Metric
lb/hr	4.536×10^{-1}	kg/hr
°F	5/9(°F-32)	°C
psi	6.895×10^{3}	Pa
gr/dscf	2.288×10^{9}	ng/dscm[a]
gr/dscf	2.288×10^{3}	mg/dscm
ton/day (tpd)	9.07×10^{-1}	tonne/day

[a]Note that "dscm" means dry standard cubic meter.

TABLE 1. FEATURES OF WASTE-TO-ENERGY UNITS TESTED

Unit Tested	Type and Rating[a]	Flue Gas Cleaning System	Test Date
Unit No. 1 Marion County Solid-Waste-to-Energy Facility, Ogden Martin Systems of Marion, Inc. Brooks, OR	Mass Burn; Ogden Martin Spreader Stoker Boiler & Combustion Control System 275 tons/day 66,000 lb steam/hr at 665 psig and 700°F	Spray Dryer Absorber (Quench Reactor) with Two-fluid Nozzles (Air/Lime Slurry) Followed by Tesisorb Injection into Venturi just Upstream of Reverse Gas-cleaned Fabric Filter (Teller System)	September 1986 February 1987 June 1987
Unit A Maine Energy Recovery Company Biddeford, ME	Refuse-derived Fuel (RDF) Detroit Stoker Spreader Stoker & Babcock and Wilcox Controlled Combustion Zone Boiler & Combustion Control System 300 tons/day 105,000 lb steam/hr at 675 psig and 760°F	Cyclone Preceding Spray Dryer Absorber with Single Rotary Atomizer (Lime Slurry Feed) Followed by Pulse-jet Air-cleaned Fabric Filter	December 1987
Unit No. 2 Wheelabrator Millbury, Inc. Millbury, MA	Mass Burn, Von Roll Reciprocating Inclined Grate and Babcock and Wilcox Boiler and Combustion Control System 750 tons/day 190,000 lb steam/hr at 850 psia and 825°F	Spray Dryer Absorber with Two-fluid Nozzles (Air/Lime Slurry) Followed by a Three-field ESP	February 1988
Unit No. 11 Mid-Connecticut Resource Recovery Facility Hartford, CT	Refuse-derived Fuel (RDF) Combustion Engineering Spreader Stoker Boiler and Combustion Control System 675 tons/day 231,000 lb steam/hr at 880 psig and 825°F	Spray Dryer Absorber with Single Rotary Atomizer (Lime Slurry Feed) Followed by Reverse Gas-cleaned Fabric Filter	July 1988

[a] English to metric unit conversions are given in the Appendix.

TABLE 2. SUMMARY OF DATA COLLECTED FOR UNITS TESTED

Unit Tested	Test Date	Sampling Location	Sample Type/Method	Quantity Measured
Unit No. 1	September	Spray Dryer Absorber	Flue Gas/MM5	CDD,CDF
Marion County Solid-Waste-to-Energy Facility, Ogden Martin	1986	(SDA) Inlet	Flue Gas/Mod. M5	PM,Pb,Cd
			Flue Gas/Mod. M5	Cr^{+3},Cr^{+6},Ni
Systems of Marion, Inc.	February	Spray Dryer Absorber	Flue Gas/MM5	CDD,CDF,HCl
Brooks, OR	1987		Flue Gas/CEM	SO_2
	September	Outlet Stack	Flue Gas/MM5	CDD,CDF
	1986		Flue Gas/Mod. M5	PM,Pb,Cd
			Flue Gas/Mod. M5	Cr^{+3},Cr^{+6},Ni
			Flue Gas/M5	PM,HCl
			Flue Gas/CEM	SO_2,NO_x,CO
		Fabric Filter (FF) Ash (Residue) Discharge	Grab	CDD,CDF
				Metals
		SDA Ash (Residue) Discharge	Grab	CDD,CDF
				Metals
		Lime Feed Slurry Return Line	Grab	Metals
		Tesisorb Feed Hopper	Grab	Metals

TABLE 2. (continued) SUMMARY OF DATA COLLECTED FOR UNITS TESTED

Unit Tested	Test Date	Sampling Location	Sample Type/Method	Quantity Measured
Unit No. 1 Marion County	June 1987	SDA Inlet	Flue Gas/MM5	CDD,CDF,HCl
			Flue Gas/M3	CO_2,O_2
			Flue Gas/CEM	CO_2,O_2,SO_2
			Flue Gas/CEM	NO_x
			Flue Gas/CEM	CO
			Flue Gas/CEM	THC
			Flue Gas/CEM	HCl
		SDA Outlet (Midpoint)	Flue Gas/M5	HCl
			Flue Gas/CEM	CO_2,O_2,SO_2
			Flue Gas/CEM	HCl
		FF Outlet	Flue Gas/MM5	CDD,CDF
			Flue Gas/M5	HCl
			Flue Gas/M3	CO_2,O_2
			Flue Gas/CEM	NO_x
			Flue Gas/CEM	CO
			Flue Gas/CEM	THC
			Flue Gas/CEM	HCl
		Superheater Ash Discharge	Grab	CDD,CDF
		Economizer Ash Discharge	Grab	CDD,CDF
		SDA Residue Discharge	Grab	CDD,CDF
		FF Residue Discharge	Grab	CDD,CDF
		Tesisorb Feed Hopper	Grab	CDD,CDF
		Lime Feed Slurry Return Line	Lime Slurry	CDD,CDF

TABLE 2. (continued) SUMMARY OF DATA COLLECTED FOR UNITS TESTED

Unit Tested	Test Date	Sampling Location	Sample Type/Method	Quantity Measured
Unit A Maine Energy Recovery Company (MERC) Biddeford, ME	December 1987	SDA Inlet	Flue Gas/MM5	CDD,CDF
			Flue Gas/Mod. M5	PM,Metals
			Flue Gas/M3	CO_2,O_2
			Flue Gas/CEM	CO_2,O_2,SO_2
			Flue Gas/CEM	CO
			Flue Gas/CEM	THC
			Flue Gas/CEM	HCl
		SDA Outlet (Midpoint)	Flue Gas/CEM	CO_2,O_2
			Flue Gas/CEM	HCl
		FF Outlet	Flue Gas/MM5	CDD,CDF
			Flue Gas/Mod. M5	PM,Metals
			Flue Gas/CEM	CO_2,O_2
			Flue Gas/CEM	CO
			Flue Gas/CEM	HCl
		Bottom Ash Discharge	Grab	Metals,C Combustibles
		Cyclone Ash Discharge	Grab	Metals,C Combustibles
		FF Residue Discharge	Grab	Metals,C Combustibles Electrical Resistivity
		Lime Slurry Feed Line	Lime Slurry	Metals

TABLE 2. (continued) SUMMARY OF DATA COLLECTED FOR UNITS TESTED

Unit Tested	Test Date	Sampling Location	Sample Type/Method	Quantity Measured
Unit No. 2 Wheelabrator Millbury, Inc. Millbury, MA	February 1988	SDA Inlet	Flue Gas/MM5 Flue Gas/M3 Flue Gas/CEM[a]	CDD,CDF CO_2,O_2 CO,O_2,SO_2
		ESP outlet	Flue Gas/MM5 Flue Gas/M3 Flue Gas/CEM	CDD,CDF CO_2,O_2 O_2,NO_x,SO_2 Opacity
		Bottom Ash Discharge	Grab	CDD,CDF,C Combustibles
		Economizer Steam Generating Bank Ash Discharge	Grab	CDD,CDF,C Combustibles
		SDA Residue Discharge	Grab	CDD,CDF,C Combustibles
		ESP Residue Discharge (Three Locations)	Grab	CDD,CDF,C Combustibles
		SDA Lime Slurry Feed Line	Lime Slurry	CDD,CDF Solids Content Specific Gravity
Unit No.11 Mid-Connecticut Resource Recovery Facility Hartford, CT	July 1988	SDA Inlet	Flue Gas/MM5 Flue Gas/M101A Flue Gas/M3	CDD,CDF Hg,PM,Metals CO_2,O_2
		FF Outlet	Flue Gas/MM5 Flue Gas/M101A Flue Gas/M3	CDD,CDF Hg,PM CO_2,O_2

[a] Continuous Emission monitor (CEM) readings were obtained from the plant's instruments.

TABLE 3. HCL CONCENTRATION AND REMOVAL

Location/Date	Run No.	HCl Concentration, ppmv (dry) @ 12% CO_2			Removal Efficiency,%		Average Temperature,°F			Ref.
		Spray Dryer Absorber		Fabric Filter or ESP	Spray Dryer Absorber	Overall System	Spray Dryer Absorber		FF or ESP	
		Inlet	Outlet[a]	Outlet			Inlet	Outlet[a]	Outlet	
Unit No. 1	1	646	225	83.7	65.2	87.0	432	300	280	6
Marion County	2	631	183	35.0	71.0	94.5	430	300	280	
Brooks, OR	Avg.	639	204	59.4	68.1	90.7	431	300	280	
June 1987	10	814	180	20.4	77.9	97.5	436	262	252	
	11A	718	295	158	58.9	78.0	434	330	302	
	11B	750	313	214	58.3	71.5	461	360	334	
Unit A	1	478	63	9	86.8	98.1	374	277	268	8
MERC	2[b]	566	8	4	98.6	99.3	364	278	268	
Biddeford, ME	3	540	1[c]	3	ND[c]	99.4	384	279	268	
December 1987	Avg.	528	36[d]	5	93.2[d]	99.1	374	278	268	
Unit No. 2	1	764	NA[e]	9.2	NA[e]	98.8	438	255	254	7
Wheelabrator	2	672	NA	4.2	NA	99.4	441	255	254	
Millbury, MA	3	574	NA	4.0	NA	99.3	432	255	253	
February 1988	Avg.	670	NA	5.8	NA	99.1	437	255	254	
Unit No. 11	1	424	NA	5.3	NA	98.8	379	270	241	9,10
Mid-Conn	2	472	NA	3.1	NA	99.3	375	266	234	
Hartford, CT	3	457	NA	4.3	NA	99.1	384	277	250	
July 1988	Avg.	451	NA	4.2	NA	99.1	379	271	242	

[a] Also referred to as midpoint.
[b] Slurry feed doubled 45 minutes into run and then held constant for remainder of this and Run 3.
[c] Questionable value and efficiency not determined (ND) for this run.
[d] Average based on Runs 1 and 2.
[e] NA means not available or not applicable.

NOTE: Average (Avg.) values and removal efficiencies were determined before rounding off; thus, the values shown may differ slightly from values calculated from listed values.

TABLE 4. SO_2 CONCENTRATIONS AND REMOVAL

Location/Date	Run No.	SO_2 Concentrations ppmv (dry) @ 12% CO_2			Removal Efficiency,%		Average Temperature , °F			Ref.
		Spray Dryer Absorber		Fabric Filter or ESP	Spray Dryer	Overall	Spray Dryer Absorber		FF or ESP	
		Inlet	Outlet[a]	Outlet	Absorber	System	Inlet	Outlet[a]	Outlet	
Unit No. 1	1	559	450	383	19.5	31.5	432	300	280	6
Marion County	2	299	128	100	57.0	66.7	430	300	280	
Brooks, OR	Avg.	429	289	241	32.6	43.7	431	300	280	
June 1987	10	383	326	108	14.8	71.8	436	262	252	
	11A	470	523	484[b]	-11.1[b]	-3.0[b]	434	330	302	
	11B	118[b]	178	165	-50.4[b]	-39.4[b]	461	360	334	
Unit A	1	83.3	NA[c]	28.4	NA	65.9	374	277	268	8
MERC	2	76.9	NA	21.2	NA	72.4	364	278	268	
Biddeford, ME	3	115	NA	12.1	NA	89.5	384	279	268	
December 1987	Avg.	91.9	NA	20.6	NA	77.6	374	278	268	
Unit No. 2	1	307	NA	56.0	NA	81.7	438	255	254	7
Wheelabrator	2	243	NA	49.5	NA	79.6	441	255	254	
Millbury, MA	3	305	NA	71.0	NA	76.7	432	255	253	
February 1988	Avg.	285	NA	58.8	NA	79.4	437	255	254	

[a] Also referred to as midpoint.
[b] Instrument inaccuracies due to measuring concentrations outside of calibration range (i.e., measuring low concentrations while calibrated to measure high concentrations).
[c] Not available.

NOTE: Average (Avg.) values and removal efficiencies were determined before rounding off; thus, the values shown may differ slightly from values calculated from listed values.

TABLE 5. AVERAGE CDD AND CDF AT SITES TESTED[a]

Location/Date	Total Uncontrolled Emissions ng/dscm at 12% CO_2			Total Controlled Emissions ng/dscm at 12% CO_2			Removal, %			Ref.
	CDD	CDF	CDD+CDF	CDD	CDF	CDD+CDF	CDD	CDF	CDD+CDF	
Unit No. 1[b] Marion County Brooks, OR September 1986 February 1987	31.2 (24.4-36.8)[c]	150 (85.6-187)	182 (110-219)	1.01 (0.69-1.34)	1.19 (0.97-1.42)	2.2 (1.66-2.76)	96.8	99.2	98.8	4
Unit A[d] MERC Biddeford, ME December 1987	288 (239-342)	590 (560-594)	877 (833-957)	1.3 (1.0-1.6)	2.9 (2.4-3.5)	4.3 (3.5-5.0)	99.5	99.5	99.5	8
Unit No. 2[e] Wheelabrator Millbury, MA February 1988	44.3 (32.6-52.2)	120.1 (96.6-153)	164.3 (142.4-205)	14.8 (9.2-30.4)	47.4 (33.8-79.7)	62.2 (41.8-110)	66.6	60.5	62.1	7
Unit No. 11[d] Mid-Conn Hartford, CT July 1988	327 (228-378)	762 (609-1010)	1090 (886-1390)	0.593 (0.267-0.776)	0.521 (0.265-0.864)	1.12 (0.532-1.64)	99.8	99.9	99.9	9,10

[a] Values of CDD and CDF do not include not-detectable congeners (i.e., those below minimum detection limits).
[b] Uncontrolled values are averages from Runs 1-4 collected by EPA in February 1987, and the controlled values are averages of Runs 2 and 3 collected by Ogden Projects, Inc., in September 1986. Low recovery of internal standards in samples collected by EPA in September 1986 led to the February 1987 tests under similar unit operating conditions.
[c] The range of values is shown in parentheses under each average value.
[d] Values indicated are based on three test runs.
[e] Values indicated are based on five test runs.

NOTE: Summed values and removals were determined before rounding off; thus, the values shown may differ slightly from those calculated using the listed values.

TABLE 6. PARTICULATE MATTER EMISSION (Corrected to 12% CO_2) AND REMOVAL

Location/Date	Run No.	Particulate Matter Emission gr/dscf: Spray Dryer Absorber Inlet	Particulate Matter Emission gr/dscf: Fabric Filter Outlet	Removal Efficiency, %	Ref.
Unit No. 1	1	1.05	0.0037	99.5	
Marion County	2	1.12	0.0018	99.8	
Brooks, OR	3	0.74	0.0013	99.8	
September 1986	Avg.	0.88[a]	0.0023	99.7[a]	4
Unit A	1	3.23	0.0095[b]	99.7	
MERC	2	2.85	0.0142	99.5	
Biddeford, ME	3	3.53	0.0194	99.5	
December 1987	Avg.	3.20	0.0144	99.6	8
Unit No. 11	1	2.72	0.0021	99.9	
Mid-Conn	2	2.32	0.0041	99.8	
Hartford, CT	3	4.92[c]	0.0059	99.9	
July 1988	Avg.	2.52[d]	0.0040	99.8	9,10

[a] Based on Runs 1-6. Inlet emission values for Runs 4, 5, and 6 were: 0.848, 0.791, and 0.739 gr/dscf, respectively

[b] Not determined from diluent data as Method 3 sampling train leaked. Inlet results to spray dryer absorber for Run 1 used to obtain corrected value.

[c] Includes sootblowing sequence.

[d] Based on Runs 1 and 2, as Run 3 included sootblowing.

NOTE: Because of rounding off of emission data, the removal efficiency may differ slightly from that listed.

TABLE 7. EMISSION RATES OF SELECTED METALS (Corrected to 12% CO_2)

Location:	Unit 1, Marion County, Brooks, OR				Unit A, MERC, Biddeford, ME				Unit 11, Mid-Conn, Hartford, CT			
Test Date:	September 1986 (Ref. 4)				December 1986 (Ref. 8)				July 1988 (Ref. 9, 10)			
Run No.	4	5	6	Avg.	1	2	3	Avg.	1	2	3	Avg.
Uncontrolled Metal, µg/dscm												
Arsenic					507	543	652	567				
Cadmium	1,150	1,180	950	1,090	1,090	1,090	1,560	1,250				
Chromium	453	262	520	412	2,520	2,750	3,970	3,080				
Lead	16,400	19,400	24,200	20,000	28,100	28,200	34,900	30,400				
Mercury					523	330	432	428	320	1,180	1,060	852
Controlled Metal, µg/dscm												
Arsenic					0.0677	2.75	3.88	2.23	<2.6	<3.0	<3.0	<2.9
Cadmium	17	2.8	2.2	2.5[a]	5.42	4.78	15.7	8.62				
Chromium	ND[b]	0.12[c]	0.19	0.16[a]	1.40	2.31	5.80	3.17	59	<50	<25	<45
Lead	180	14	21	18[a]	68.4	72.9	185	109	<5	<5	<7	<6
Mercury					ND[a]	0.8	2.8	1.8	62	2	8	24
Removal Efficiency, %												
Arsenic					99.9	99.5	99.4	99.6				
Cadmium	98.5	99.8	99.8	99.8	99.5	99.6	99.0	99.4				
Chromium	100	99.9	99.9	99.9	99.9	99.9	99.9	99.9				
Lead	98.9	99.9	99.9	99.9	99.8	99.7	99.5	99.7				
Mercury						99.8	99.4	99.6	80.6	99.8	99.3	97.2

[a] Average of Runs 5 and 6 as baghouse was bypassed during Run 4, causing higher emissions.
[b] ND means none detected.
[c] Analyte detected at detection limit.

NOTE: Blank spaces indicate no data collected or insufficient data to calculate efficiency.

TABLE 8. SUMMARY OF AVERAGE REMOVAL EFFICIENCIES (%) IN MWC FLUE GAS CLEANING SYSTEMS

Type of MWC	Mass Burn		Refuse-derived Fuel (RDF)	
Unit/Location	1/Marion County	2/Millbury	A/Biddeford	11/Mid-Conn
Flue Gas Cleaning System	SDA/FF	SDA/ESP	SDA/FF	SDA/FF
Pollutants				
Acid Gas				
HCl	90.7	99.1	99.1	99.1
SO_2	43.7	79.4	77.6	NA[a]
Organics				
CDD	96.8	66.6	99.5	99.8
CDF	99.2	60.5	99.5	99.9
CDD+CDF	98.8	62.1	99.5	99.9
Particulate Matter	99.7	NA	99.6	99.8
Metal				
Arsenic	NA	NA	99.6	NA
Cadmium	99.8	NA	99.4	NA
Chromium (total)	99.9	NA	99.9	NA
Lead	99.9	NA	99.7	NA
Mercury	NA	NA	99.6	97.2

[a] NA means not available.

NOTE: All efficiencies are based on mass.

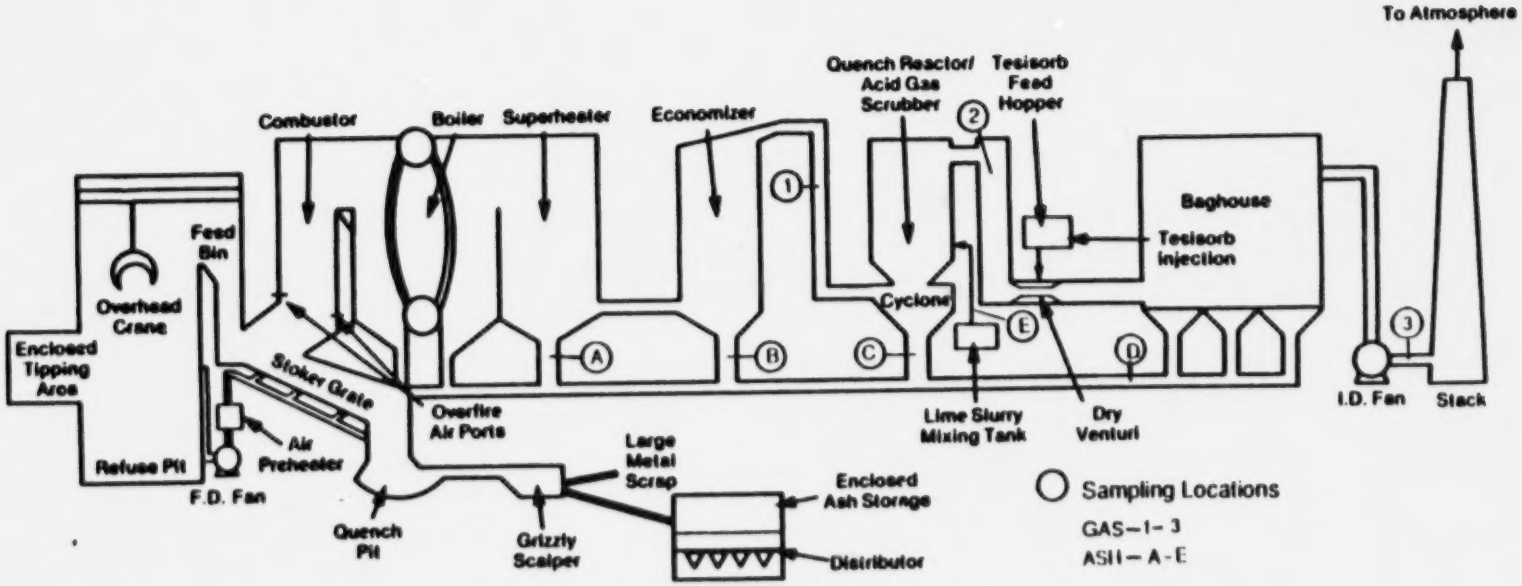

Figure 1. Flow diagram for incinerator Unit 1 of the Marion County Solid-Waste-to-Energy Facility. (6)

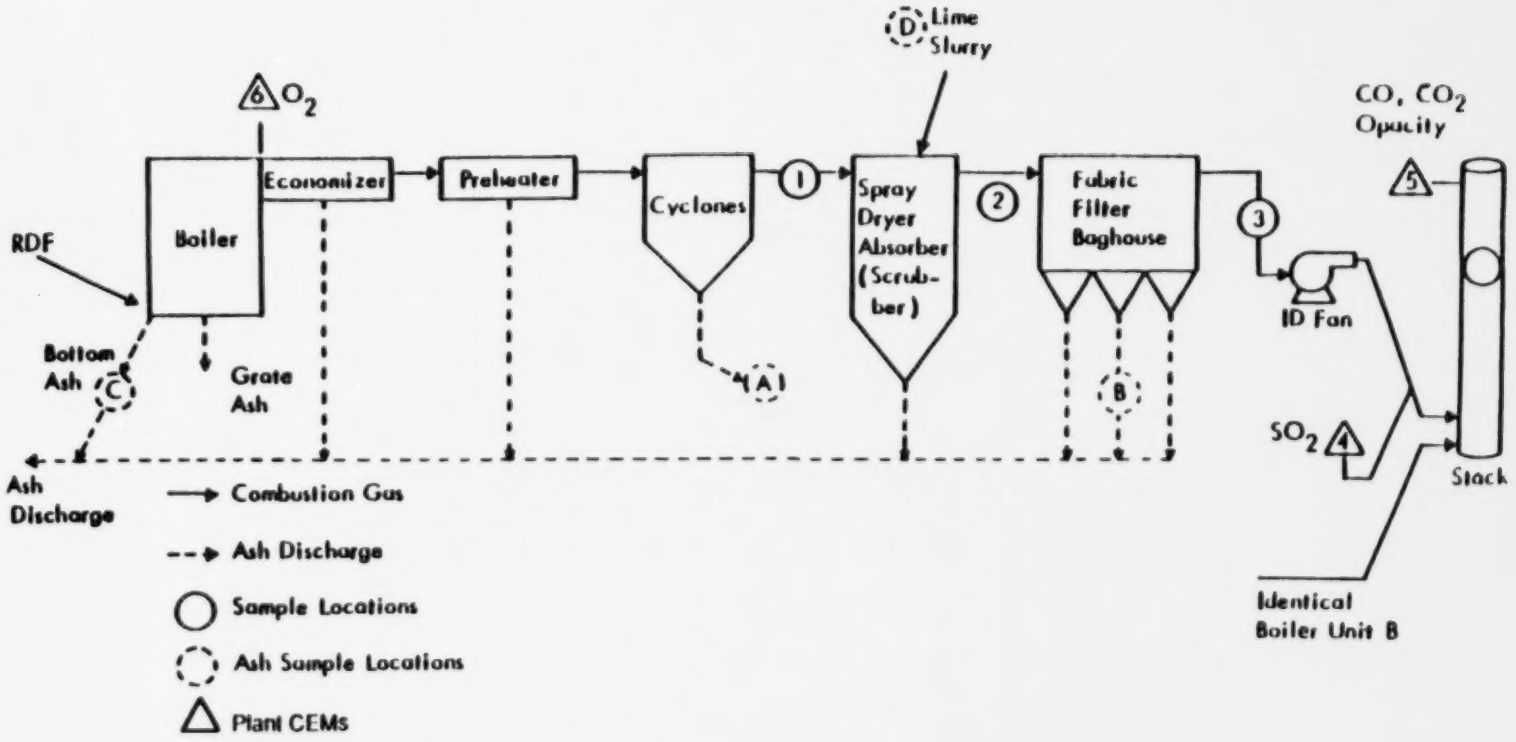

Figure 2. Process flow diagram for Unit A, Maine Energy Resource Company, with sampling locations.

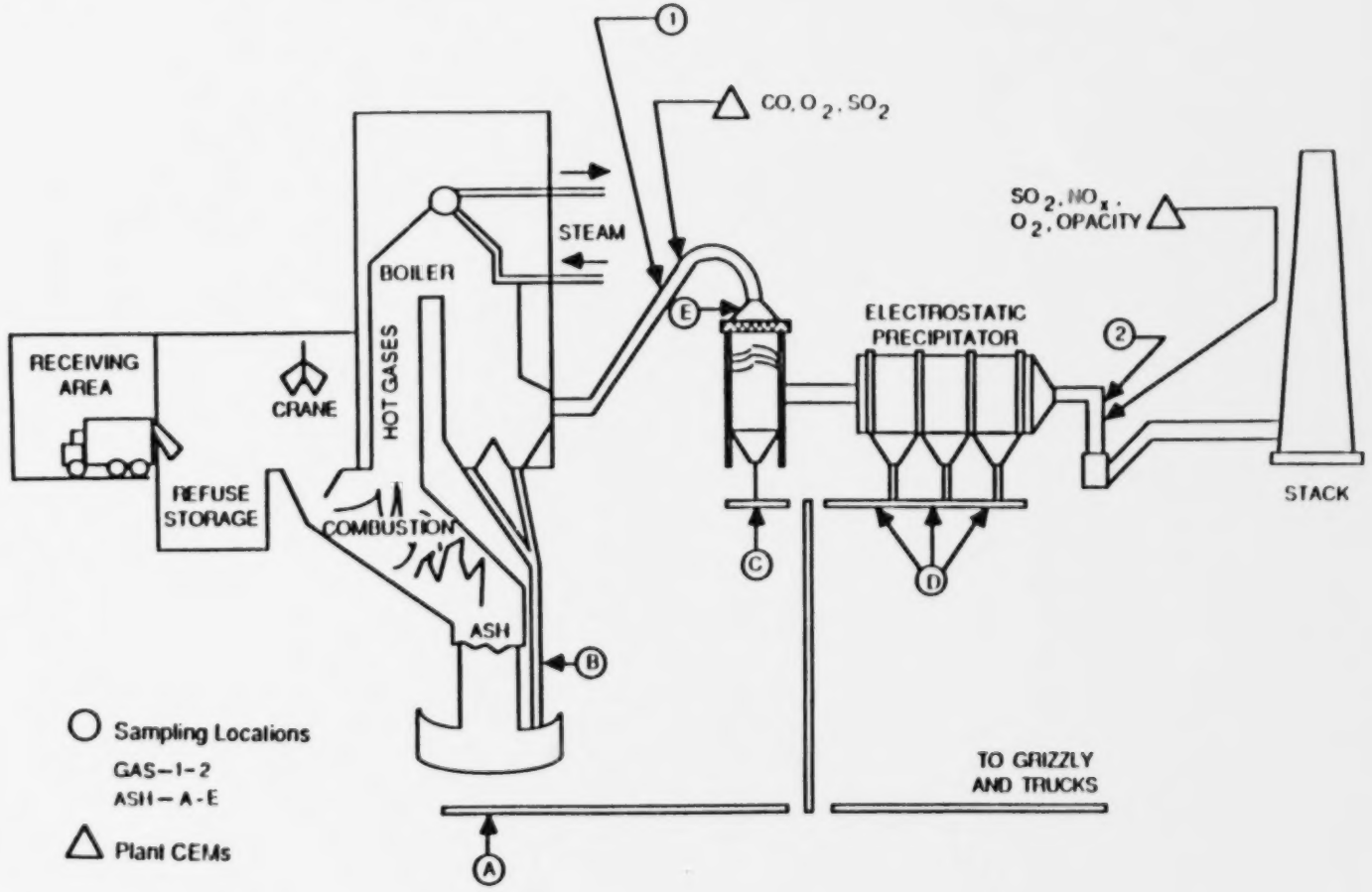

Figure 3. Process schematic showing sampling locations for one of two MWC units (Unit 2) at the Millbury Resource Recovery Facility. (7)

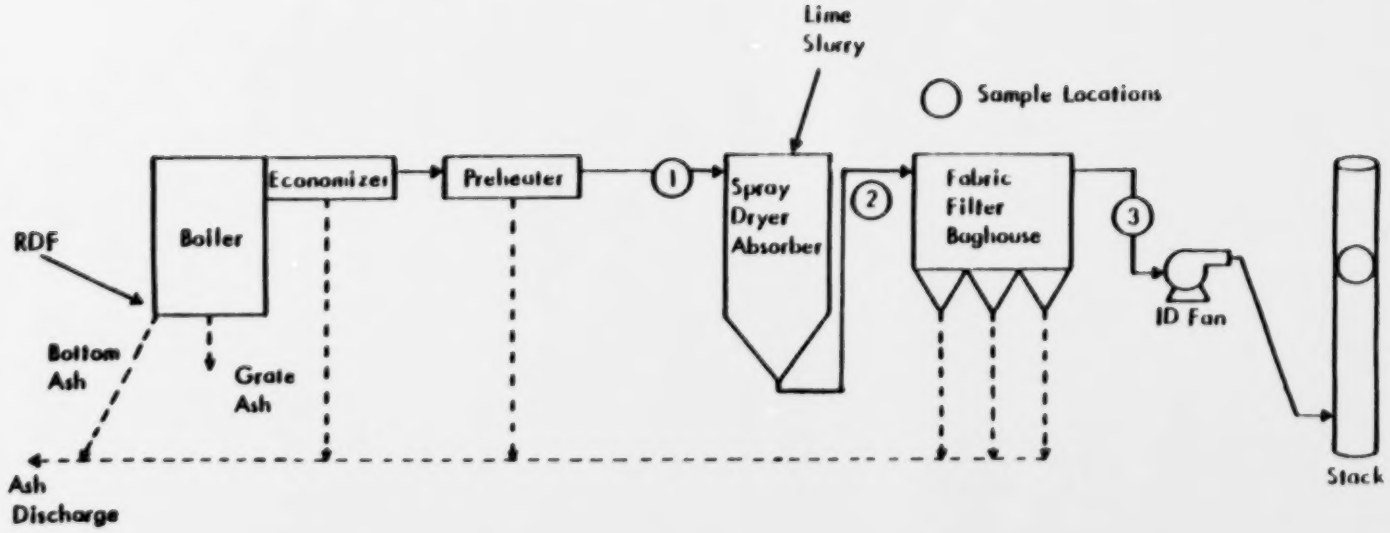

Figure 4. Process flow diagram for Unit 11, Connecticut Resource Recovery Facility, with gas sampling locations noted.